2005-03

Scheduling ammunition loading and unloading for U.S. Navy ships in San Diego

Billings, Roger L.

Monterey, California. Naval Postgraduate School

http://hdl.handle.net/10945/2318

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

SCHEDULING AMMUNITION LOADING AND UNLOADING FOR U.S. NAVY SHIPS IN SAN DIEGO

by

Roger L. Billings

March 2005

Thesis Advisor:	Robert F. Dell
Second Reader:	Glenn J. Lintz

Approved for public release; distribution is unlimited.

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** March 2005	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Title (Mix case letters) **Scheduling Ammunition Loading and Unloading for U.S. Navy Ships in San Diego**			**5. FUNDING NUMBERS**
6. AUTHOR(S) Billings, Roger L.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) Commander, Naval Surface Force Pacific San Diego, CA			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

Tomahawk cruise missiles (TCM) cost over one million dollars and are in short supply. U.S. Navy ships require TCM and other conventional ammunition be loaded in appropriate amounts prior to deploying to sea. A typical deployment lasts for six months and, when completed, any remaining ammunition must be unloaded and made ready for other deploying ships. For ships under Commander, Naval Surface Force U.S. Pacific Fleet (SURFPAC), about 3,500 tons of ammunition must be loaded and unloaded annually; this currently costs 14 million dollars for just pilots, tugboats and fuel. This thesis formulates and solves an integer linear program, Surface Navy Scheduler (SNSKED), to prescribe an ammunition load and unload schedule for San Diego homeported ships. SNSKED seeks a schedule with minimized costs subject to constraints on ships availability, port capabilities and support assets. We test SNSKED on a realistic quarterly scenario consisting of 19 combatant ships, three weapons stations, two ammunition ships, five mission types, two ammunition types, and three ways of loading ammunition. SNSKED provides optimal schedules that reduce costs by over 16 percent. We also use SNSKED to evaluate different operational policies, ammunition port utilization, and ammunition loading times.

14. SUBJECT TERMS Mixed Integer Linear Programming, Ships Scheduling, Optimization, Ordnance, GAMS.			**15. NUMBER OF PAGES** 58
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

SCHEDULING AMMUNITION LOADING AND UNLOADING FOR U.S. NAVY SHIPS IN SAN DIEGO

Roger L. Billings
Lieutenant Commander, United States Navy
B.S., University of Kansas, 1991

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
March 2005

Author: Roger L. Billings

Approved by: Robert F. Dell
Thesis Advisor

Glenn J. Lintz
Second Reader

James N. Eagle
Chairman, Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Tomahawk cruise missiles (TCM) cost over one million dollars and are in short supply. U.S. Navy ships require TCM and other conventional ammunition be loaded in appropriate amounts prior to deploying to sea. A typical deployment lasts for six months and, when completed, any remaining ammunition must be unloaded and made ready for other deploying ships. For ships under Commander, Naval Surface Force U.S. Pacific Fleet (SURFPAC), about 3,500 tons of ammunition must be loaded and unloaded annually; this currently costs 14 million dollars for just pilots, tugboats and fuel. This thesis formulates and solves an integer linear program, Surface Navy Scheduler (SNSKED), to prescribe an ammunition load and unload schedule for San Diego homeported ships. SNSKED seeks a schedule with minimized costs subject to constraints on ships availability, port capabilities and support assets. We test SNSKED on a realistic quarterly scenario consisting of 19 combatant ships, three weapons stations, two ammunition ships, five mission types, two ammunition types, and three ways of loading ammunition. SNSKED provides optimal schedules that reduce costs by over 16 percent. We also use SNSKED to evaluate different operational policies, ammunition port utilization, and ammunition loading times.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGEMENTS

I would like to thank SURFPAC N41, in particular CDR Robert Heck and TMMC(SW) Vaughan, for providing financial and technical support. Without it, this thesis would not have been possible.

I thank LT Stanley of AMMOPAC for his willingness to provide much needed technical support. His in-depth knowledge and enthusiasm significantly improved my understanding of the problem.

Particular thanks to CDR Glenn Lintz for graciously giving his time so I could complete this thesis on time.

Special thanks to Dr. Robert Dell for his guidance and patience throughout this arduous project. You gave me a generous portion of your time and always had an encouraging word. The quality of this study is due largely to his insight, perseverance, and editorial effort.

Most importantly, I thank my mother Della Billings and father Marvin Billings for their devotion and for providing me with the inspiration to persist.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ABBREVIATIONS AND ACRONYMS

AMMOPAC	Ammunition Management Office Pacific
CD OP	Counter Drug Operations
CG	Guided Missile Cruiser
CV	Carrier
DDG	Guided Missile Destroyer
FFG	Guided Missile Frigate
IDTC	Inter-Deployment Training Cycle
LHA	Amphibious Helicopter Assault Carrier
LHD	Amphibious Helicopter Assault Carrier Dock
LPD	Amphibious Transport Dock
LSD	Dock Landing Ship
SM2	Standard Missiles Type Two
SNSKED	Surface Navy Scheduler
SRA	Ships Restricted Availability
SURFPAC	Naval Surface Force U.S. Pacific Fleet
T-AE	Auxiliary Ammunition Carrier
T-AOE	Supply Fast Combat Support Ship
T-AKE	Auxiliary Dry Cargo Carrier
TCM	Tomahawk Cruise Missiles
UNREP	Underway Replenishment
VERTREP	Vertical Replenishment
VLA	Vertical Launched Anti-Submarine Rockets
WESTPAC	Western Pacific Deployment

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

During a typical year, Commander, Naval Surface Force U.S. Pacific Fleet (SURFPAC) loads and unloads about 3,500 tons of ammunition on the 39 surface ships homeported in San Diego, California. SURFPAC loads ammunition on these ships before they commence one of five different deployments that last for at least six months. When the deployments are completed, any remaining ammunition must be unloaded and made ready for other deploying ships.

Currently, loading and unloading these ships costs over 14 million dollars annually for just pilots, tugboats and fuel. SURFPAC ships load and unload ammunition at Seal Beach, San Diego, and Fallbrook or while underway. U.S. Navy policy requires that San Diego account for only 20 percent of all ammunition loadings. There are three different ways to load the ammunition: pier-side, vertical replenishment or barge.

This thesis formulates and solves an integer linear program, Surface Navy Scheduler (SNSKED), to prescribe an ammunition load and unload schedule for San Diego homeported ships. SNSKED seeks a schedule with minimized costs subject to constraints on ships' availability, port capabilities, and support assets. We test SNSKED on a realistic quarterly scenario consisting of 19 combatant ships, three weapons stations, two ammunition ships, five mission types, two ammunitions groups, and three ways of loading ammunition.

For all scenarios, we divide ammunition into two different groups, TCM and other ammunition. TCM warrants a separate category because there is a considerable TCM requirement Fifth and Seventh Fleet areas of responsibility and a known inventory scarcity.

A typical SNSKED instance consists of approximately 1,700 equations, 5,700 continuous variables, 4,500 discrete variables, 19,000 non-zero elements and solves in less than three minutes. SNSKED provides optimal schedules that reduce costs for SURFPAC by over sixteen percent.

We also use SNSKED to evaluate changes in operational policies, ammunition port utilization and differing ammunition loading times. SNSKED suggests that a

savings of almost two million dollars per quarter is possible. These savings could be used to offset the costs of improvements to San Diego ammunition pier capabilities and ammunition inventory increases.

This thesis demonstrates the potential to save money and serves as a tool to analyze the impact of changes in port facilities and policies governing SURFPAC and Ammunition Management Office Pacific (AMMOPAC) operations.

I. INTRODUCTION

During a typical year, Commander, Naval Surface Force U.S. Pacific Fleet (SURFPAC) loads and unloads about 3,500 tons of ammunition on the 39 surface ships homeported in San Diego, California. SURFPAC uses three weapons stations (Naval Station San Diego, Weapons Station Seal Beach, and Weapons Station Fallbrook) and vertical replenishment (VERTREP) to complete these loadings. Table 1 and Figure 1 show their geographical proximity to San Diego.

Weapons Station	**Distance to Travel from San Diego 32nd Street piers (one way)**	**Time to Travel from San Diego 32nd Street piers (one way)**
San Diego	4 Nautical Miles	1 Hour
Fallbrook	45 Nautical Miles	4 Hours
Seal Beach	90 Nautical Miles	7 Hours
VERTREP area	25 Nautical Miles	3 Hours

Table 1. Distance and time from San Diego 32nd Street piers to the Weapons Stations. The travel time includes the time needed to negotiate the busy shipping channels near San Diego and Los Angeles. The VERTREP area is due west of San Diego.

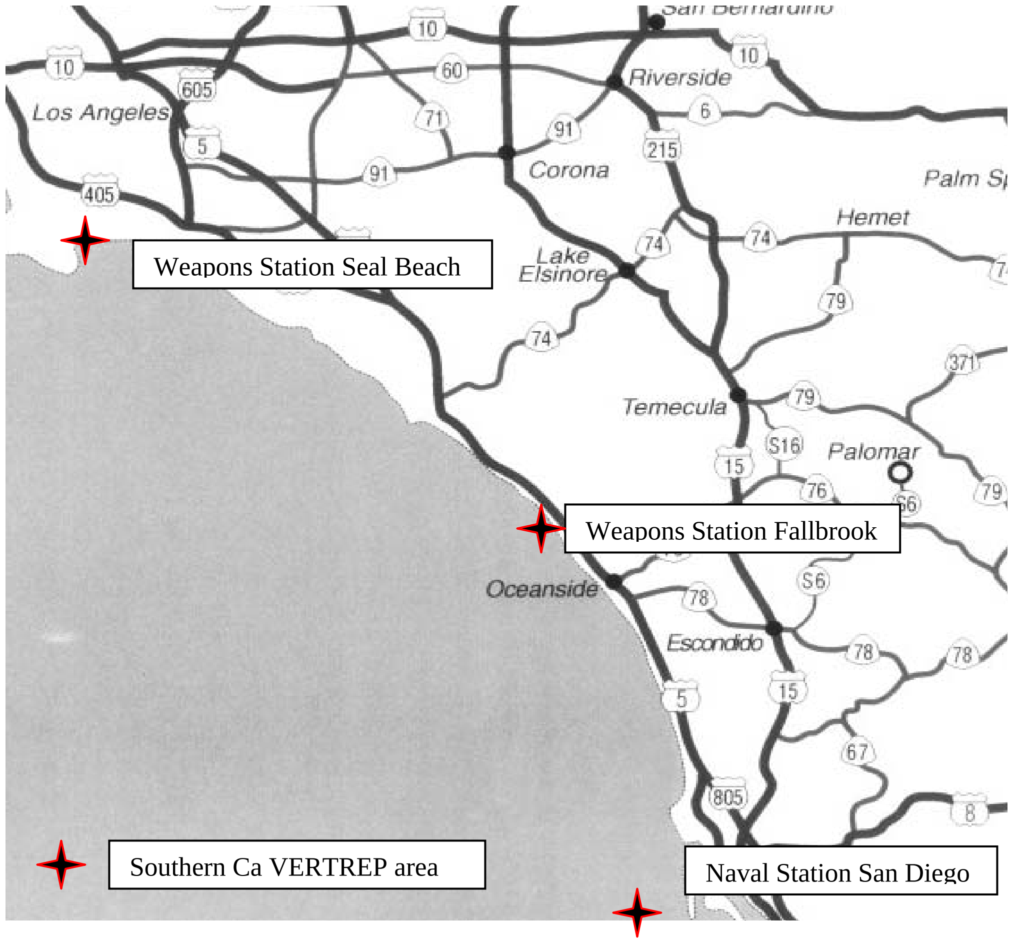

Figure 1. Map of Southern California Ammunition Bases. [Google Maps 2005].

To fulfill ammunition requirements, SURFPAC spends over three and one half million dollars per quarter in fuel, tugboats and pilot costs shuttling ships between San Diego and Seal Beach [Vaughan 2004]. The purpose of this thesis is to evaluate ammunition loading alternatives that attempt to minimize costs while providing an equal level of service. This thesis provides a mixed integer linear program, Surface Navy Scheduler (SNSKED), to compare ammunition loading and unloading schedules. SNSKED minimizes the costs to SURFPAC and provides an evaluation of how tailored asset reallocation can reduce the overall cost of ammunition movements.

A. SHIP CLASSES

Table 2 shows all ship classes and the number of ships homeported in San Diego and funded by SURFPAC. Other classes of ships, such as submarines, receive no funding from SURFPAC and are not included in SNSKED. Table 2 also shows the allotted time given to load or unload a ship at a feasible weapons facility for a given ship class (Historical Variable Workload for all Weapons Stations for Ammunition Management Office Pacific [HVW 1998]). Additional staffing and equipment could reduce these times [Vaughan 2004] and we use SNSKED to evaluate the overall cost benefit by changing these "days to load."

Ship Class	**Number of Ships homeported in San Diego**	**Overall Length**	**Port capable of accepting ship class**	**Days to Load or Unload**
Guided Missile Frigate (FFG)	6	453 Feet	San Diego, Seal Beach, VERTREP, Fallbrook	1
Guided Missile Destroyer (DDG)	13	505 Feet	San Diego, Seal Beach	3
Guided Missile Cruiser (CG)	6	567 Feet	San Diego, Seal Beach	3
Dock Landing Ship (LSD)	4	610 Feet	Seal Beach, VERTREP, Fallbrook	1
Amphibious Transport Dock (LPD)	5	648 Feet	Seal Beach, VERTREP, Fallbrook	5
Amphibious Helicopter Assault Carrier (LHA)	3	820 Feet	Seal Beach, VERTREP, Fallbrook	5
Amphibious Helicopter Assault Carrier Dock (LHD)	2	844 Feet	Seal Beach, VERTREP, Fallbrook	2

Table 2. SURFPAC ship composition, characteristics, and ammunition loading capabilities.

B. PORT CAPABILITES

1. Seal Beach

Seal Beach (Figure 2) has more capability than the other weapons stations in southern California. It is one of only two port facilities capable of loading and unloading Tomahawk Cruise Missiles (TCM), Standard Missile Type Two (SM2) and Vertical Launched Anti-Submarine Rockets (VLA) into a CG or DDG MK 41 Vertical Launching System (Figure 3). It can perform pier-side loading and unloading of the following ship classes: CG, DDG, FFG, LPD, and LSD. Seal Beach can also load LHA or LHD class ships using a barge while they are at anchor just outside the quay breakwater (Figure 2).

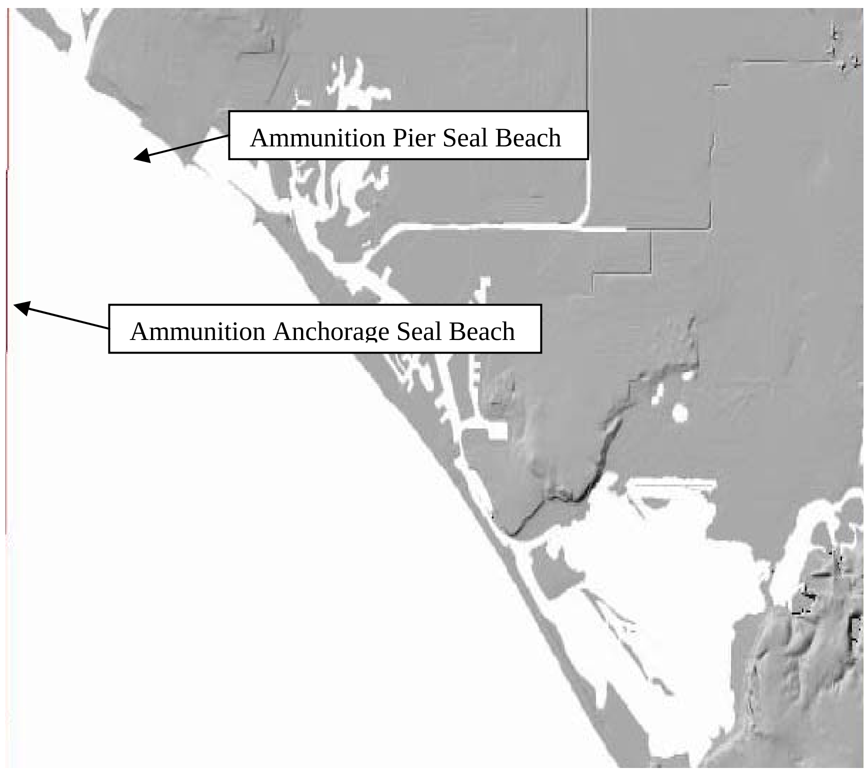

Figure 2. Location of the ammunition pier and barge loading area in Weapons Station Seal Beach. [From Global 2005].

Naval Weapons Station Seal Beach is currently responsible for 80% of all ammunition loading for San Diego homeported ships and is the site of the TCM, SM2 and VLA missile repair and modernization facilities (Naval Base Coronado Weapons Program Mission Statement [NPCWPMS 2004]). Ammunition Management Office

Pacific (AMMOPAC) would prefer to do all TCM, SM2 and VLA transfers at Seal Beach to mitigate their transportation cost and quicken missile repair time.

Figure 3. MK41 VLS being loaded pier-side. Because of stability issues, MK41 VLS cannot be loaded or unloaded at sea. [From Global 2005].

2. San Diego

The weapons pier in San Diego, located just inside the entrance to San Diego Harbor (Figure 4), loads and unloads the same class of ships pier-side and the same ammunition as Seal Beach. San Diego has staffing and equipment to handle 20% of the ammunition requirements for San Diego homeported ships [NPCWP 1986]. Ships that stay overnight at the weapons pier risk changing tides that can cause them to push off the pier. Because the weapons pier is located near the mouth of the harbor, tidal changes can be extreme. At night, there is also a lack of habitability necessities and it is difficult to provide appropriate force protection. An increased staffing level, upgraded capability, and improvement to the pier in San Diego could alleviate SURFPAC movement costs and reduce fuel costs but would require upgrades to the current capabilities [NPCWPMS 2004].

San Diego does provide some ammunition movements using a barge but only in very small amounts and only to piers one and two. The ammunition pier and pier one and two are the only piers that have a safe explosive area around them. Vertical replenishment (VERTREP) transfers are also possible from San Diego but do not occur frequently because of the long distances between the weapons loading area and the ships at sea. VERTREP of ammunition to a ship on any pier in San Diego is not permitted because the helicopters would fly over populated areas [NPCWP 1986].

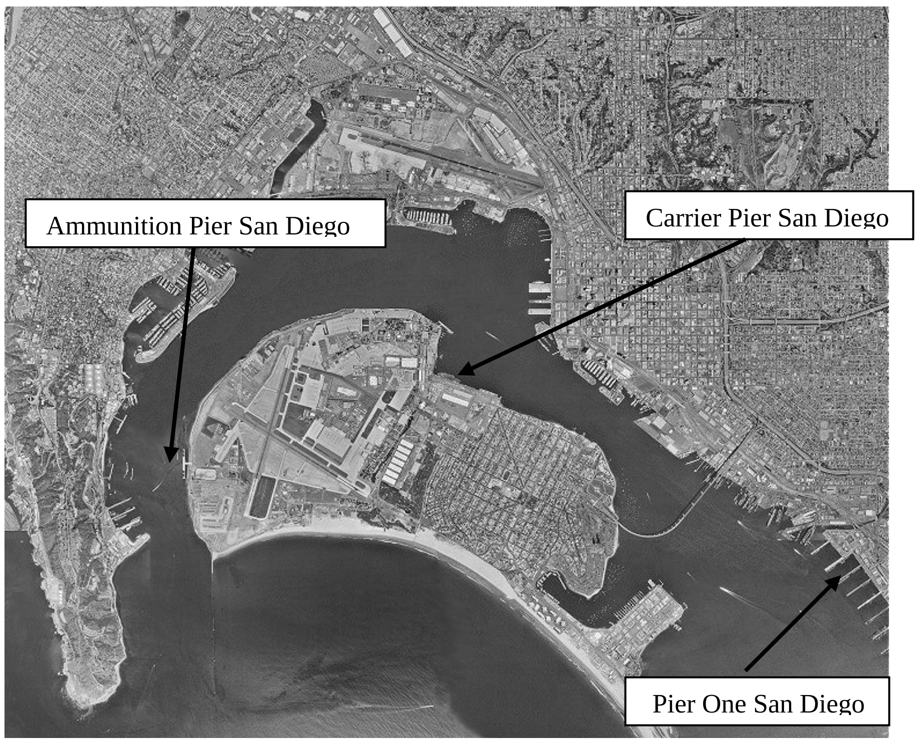

Figure 4. Naval Station San Diego, California with location of Ammunition Pier, Carrier Pier and Pier One at 32nd Street Naval Station. [From Global 2005].

3. Fallbrook

Fallbrook can handle all ammunition requirements for FFG, LHA, LHD, LPD and LSD ship classes using VERTREP (there is no pier facility). The anchorage area for all ships is only 400 yards off shore and is easily reached by VERTREP helicopters. Barges, used in the past, became cost prohibitive because the tugboats needed to move the barges have to travel from Long Beach [Bouveron 1995].

Figure 5. Weapons Station Fallbrook conducts all ammunition transfers by VERTREP from pre-staged ammunition ashore to ships. [From Global 2005].

4. VERTREP

The WESTPAC deployed ammunition ship (T-AE) has excess capacity that is usable for more ammunition in the Fifth Fleet and Seventh Fleet operating areas [Vaughan 2004]. This excess capacity could enable the transfer of ammunition from ships that have completed their deployments to ships that are just starting their deployments. This could alleviate some of the pier-side ammunition loading requirements and thus lessen the time needed to load ships. All cross deck transfers would have to happen underway using VERTREP because ammunition transfers at foreign ports are not authorized (Office of the Chief of Naval Operations instruction 8010.12 [OPNAVINST 8010.12]). The T-AE's could also carry TCM, SM2 and VLA but have no ability to load them into a MK-41 launcher.

A T-AE or T-AKE operating in the San Diego area would allow relatively fast ammunition transfers, and thereby lower the cost of doing VERTREP from Naval Station

San Diego. For a T-AE or T-AKE class ship to perform this mission, they would have to be homeported in San Diego or travel from their homeport in Bremerton, Washington.

C. STANDARDIZED AMMUNITION PACKAGES

A new directive from SURFPAC [Vaughan 2004] is to have standardized ammunition packages for the five distinct ship employment categories: Western Pacific (WESTPAC), post-deployment stand down period (Stand Down), Counter-Drug Operations (CD OP), Ships Repair Availability (SRA) and Surge Capacity. Due to shortages in Tomahawk Cruise Missiles (TCM), ships returning from deployment transfer their TCM to the next WESTPAC deploying or Surge Capacity ship. Additionally, under the new Surge Capacity structure, all ships must maintain a significant amount of SM2 and TCM onboard for Surge Capacity status, thereby stretching an already limited resource.

Prior to standardized ammunition packages, AMMOPAC, the individual ship, and SURFPAC, held a conference during the Inter-Deployment Training Cycle (IDTC) [OPNAVINST 8010.12], to determine ammunition quantities. The result of these conferences was that every ship would have a tailored munitions package for their next deployment. This often resulted in differing ammunition loads for ships in the same class.

The revised IDTC plan is to have; at most, two ammunition loads for all deploying ships and single ammunition unload after completing the deployment or Surge Capacity period. The amount of ammunition unloaded will depend on what type of mission the returning ship has scheduled next. Each ship class will have a preset ammunition quantity adhered to for every deployment type.

SURFPAC cannot strictly adhere to these new standardized ammunition packages because of the lack of TCM in inventory and the requirement, by the 2001 extension to the 1954 Mutual Defense Treaty (U. S. Department of State [DOS 2005]), to have large numbers of TCM forward-deployed in Fifth Fleet and Seventh Fleet operating areas. This thesis uses the new standardized ammunition package amounts provided by SURFPAC [Vaughan 2004] to allow SNSKED to better represent the future design of ammunition scheduling.

D. PROBLEM STATEMENT AND THESIS OUTLINE

The variety and pace of United States Navy operations over the past decade have greatly increased. Ammunition loading costs have also increased. Increased costs are due to shuttling of ships' schedules, lack of ammunition loading primacy, and inefficient ship movements. In order to reduce ammunition loading costs, SURFPAC is seeking a better ship scheduling and ammunition asset allocation and is willing to consider additional utilization of the San Diego port facilities for ammunition loading and unloading.

The objective of this thesis is to reduce ammunition loading costs while ensuring deploying ships are properly loaded and ready for deployment or surge. Reduction in overall cost is accomplished by optimizing ships' loading schedules, ammunition positioning, loading sites and quantities. This thesis offers the ability to alter current loading and scheduling capabilities for analytical comparison of cost benefits.

Chapter II provides an overview of related research. Chapter III describes the model (SNSKED) and contains assumptions and requirements, model formulation and derivations of sets. Chapter IV discusses the computational results of implementing SNSKED with various starting conditions. Finally, Chapter V presents conclusions and recommendations.

THIS PAGE INTENTIONALLY LEFT BLANK

II. RELATED RESEARCH

Recent operations research literature and commercial practices provide many examples of optimal ship scheduling and models. However, none of this literature coordinates ammunition or missile loading with ship schedules. Commercial practice does not address the ability to transfer commodities while ships are at sea or by using a barge. Another difference between commercial practices and U.S. Navy scheduling is that port capacity is not addressed. SNSKED is not trying to move items permanently; it plans for their deployment at sea in a given region of the world. Then, assuming the ammunition is not needed; it is transferred to the next deploying ship or is placed in storage.

A. COMMERCIAL SHIP SCHEDULING MODELS

Most ship scheduling models found in the operations research literature address problems faced by commercial shipping companies. Ronen [1983] discusses the variety and complexity of ship scheduling problems and proposes a model classification scheme. Most of these models concern a fleet of ships moving multiple goods from one or more supply points to various demand points. The objectives are to either minimize the number of ships required in the fleet or minimize the transportation costs using a set number of ships. None of these models addresses multiple loading points or multiple ammunition types as we use in SNSKED.

B. MILITARY SEALIFT SHIP SCHEDULING MODELS

Military sealift models are similar to commercial models. They seek to move multiple goods from several embarkation ports to numerous disembarkation ports with a set number of ships in as little time as possible. Lima [1988] uses an integer program that builds on the network flow model developed by Dantzig and Fulkerson [1954]. Lima uses column-generation to solve this integer program.

Morton, et al. [2002] develop a specialized multi-stage stochastic mixed-integer program to optimize military sealift subject to attack. The "Stochastic Sealift Deployment Model" proactively plans for potential disruptions caused by enemy attacks and illustrates the benefit of using the model with realistic deployment data. Their model design provides insight into tactical and strategic issues associated with military sealift.

These military sealift models do not address the ship ammunition requirements, the ability to transfer and store ammunition at sea, or the need to have a set amount of ammunition and missiles in a fleet for extended periods.

C. U.S. NAVY / COAST GUARD SCHEDULING MODELS

As described in Farmer [1992], Ratliff [1981] is the first to explore the possibilities of using an integer program for scheduling a portion of the U.S. Navy's Atlantic Fleet. Ratliff and Nulty [1986] extend this model by viewing each individual ship's schedule as a network and solving it as a longest path problem.

Goodman [1985], followed by Brown et al. [1990], develops an efficient algorithm for scheduling surface combatants of the Atlantic Fleet titled CPSKED. They use an elastic set partitioning model to select the best set of candidate schedules. CPSKED matches ships capabilities (armament and communication) with missions of varied durations. These considerations are not applicable to this thesis, because SURFPAC assigns the mission and ammunition quantities leaving SNSKED to determine port and date.

Sibre [1977] develops a model to solve Coast Guard Pacific Area scheduling of Hamilton Class High Endurance Cutters. The primary use of his linear programming model is to determine the length of the patrols.

Using an elastic mixed integer linear program Farmer [1992] and Brown et al. [1996] provide the First Coast Guard District a quarterly schedule that must adhere to a number of guidelines, which ensure patrol coverage, enforce equitable distribution of patrols and restrict consecutive cutter statuses.

In general, none of these models address the need to have a set amount of TCM and ammunition in a fleet for extended periods. These models do not address the need to minimize SURFPAC costs while addressing the scheduling issues associated with U.S. Navy ship movements.

D. U.S. NAVY AMMUNITION TRANSFER COSTS AND SAFETY STUDY

Bouveron [1995] does a cost analysis on changing ammunition loads for LHA, LPD, CV (Carrier), T-AOE and T-AE classes of ships. The analysis shows the practicality of doing VERTREP ammunition operations during a pre-deployment loading to provide a more cost effective ammunition transfer while observing all munitions handling regulations and safety procedures. The main comparison of munitions transfer is between VERTREP operations from Fallbrook and barge operations at Seal Beach. Bouverons' study addresses the cost of pilots and tugboats. This thesis also includes fuel expenses.

THIS PAGE INTENTIONALLY LEFT BLANK

III. SNSKED FORMULATION

A. ASSUMPTIONS AND REQUIREMENTS

SNSKED assumes daily resolution and a quarterly schedule is suitable. Additionally, the model enforces all port limitations regarding usage, which include:

- A maximum of number of ships pier-side per day and restrictions on certain ships loading and unloading only at specific ports.

- Only certain ports obtain new ammunition and this ammunition arrives at a specific rate.

- Each port has a maximum storage capability for TCM and ammunition, and the two types of ammunition are not stored together.

- Ports are restricted to their current ship capabilities listed in Table 2 (Chapter I).

- All San Diego ships load ammunition in San Diego, Fallbrook, Seal Beach or by VERTREP.

- Ships that do not have TCM load requirements are eligible for loading and unloading using an Ammunition Ship (T-AE) or Fast Combat Support Ship (T-AOE) [HVW 1998] while underway.

SNSKED divides the missions into the five distinct ship employment categories as discussed in Chapter I. No ships receive assignment to more than one mission type on a given day but ships might have assignments to multiple missions at differing times in a quarter.

We divide ammunition into two different categories, TCM and other ammunition, because of different loading requirements and available TCM inventory. SM2 and VLA are only included in the ammunition weights. There is a known scarcity of TCM in inventory and there are considerable requirements for TCM in Fifth and Seventh Fleet areas of responsibility. Management of these critical assets is imperative.

B. MODEL FORMULATION

This section shows the indices, sets, data, decision variables and the mathematical formulation of the SNSKED.

Indices:

m	mission type	(West Pac, IDTC, CD, SRA, Surge);
p	port or support ship	(San Diego, Seal Beach, Fallbrook, Underway);
s	ships	(5 FFG, 14 DDG, 6 CG…, 4 LSD);
t	working days per quarter	(1, 2, 3… 64).

Sets:

Periodavail_t	The sets of ship "s" and mission "m" that are available at time "t";
Portuse_s	Ports capable of loading ship "s";
Shipavailon_{ms}	Period ships of type "s" are available to start load for mission "m";
Shipavailoff_{ms}	Period ships of type "s" are available to start unload for mission "m".

Data:

cost_{ps}	Cost to load or unload ship of type "s" in port "p";
maxship_{pt}	Maximum number of ships in port "p" on day "t";
maxtoms_t	Maximum number of Tomahawk Cruise Missiles allowed in port "p" at the start of any day;

$maxton_t$	Maximum tons of ammunition allowed in port “p” at the start of any day;
$newammo_{pt}$	Amount of new ammunition available in port “p” at the start of day “t”;
$newtoms_{pt}$	Number of new Tomahawk Cruise Missiles available in port “p” at the start of day “t”;
$shipsize_s$	Size equivalency of ship “s” to a frigate;
$tomship_{ms}$	Number of Tomahawk Cruise Missiles required for ship “s” for mission “m”;
$tonsship_{ms}$	Ammunition loaded ship “s” for mission “m”.

Nonnegative Decision Variables:

A_{pt}	Tons of ammunition available in port “p” at the start of day “t”;
M_{pt}	Number of TCM available in port “p” at the start of day “t”.

Binary Decision Variables:

OFF_{mspt}	1	If Ship “s” assigned to port “p” to start unload on day “t” for mission “m”;
	0	Otherwise;
ON_{mspt}	1	If Ship “s” assigned to port “p” to start load on day “t” for mission “m”;
	0	Otherwise.

Mathematical Formulation:

Minimize the Objective Function…

$$\sum_{t} \sum_{m,s \in Periodavail_t} \sum_{p \in Portuse_s} cost_{ps} (ON_{mspt} + OFF_{mspt})$$

<u>Subject To:</u>

$$A_{pt} = A_{pt-1} + newammo_{pt} + \sum_{m,s \in Periodavail_t} tonsship_{ms} OFF_{mspt} - \sum_{m,s \in Periodavail_t} tonsship_{ms} ON_{mspt} \qquad \forall p,t \neq 0 \qquad (C1)$$

$$A_{pt} = newammo_{pt} \qquad \forall p,t=0 \qquad (C2)$$

$$M_{pt} = M_{pt-1} + newtoms_{pt} + \sum_{m,s \in Periodavail_t} tomship_{ms} OFF_{mspt} - \sum_{m,s \in Periodavail_t} tomship_{ms} ON_{mspt} \qquad \forall p,t \neq 0 \qquad (C3)$$

$$M_{pt} = newtoms_{pt} \qquad \forall p,t=0 \qquad (C4)$$

$$\sum_{m,s \in Periodavail_t} (shipsize_s ON_{mspt}) + \sum_{m,s \in Periodavail_t} (shipsize_s OFF_{mspt}) \leq maxship_{pt} \qquad \forall p,t \qquad (C5)$$

$$A_{pt} \leq maxton_t \qquad \forall p,t \qquad (C6)$$

$$M_{pt} \leq maxtoms_t \qquad \forall p,t \qquad (C7)$$

$$\sum_{t \in Shipavail_{ms}} \sum_{p \in Portuse_s} OFF_{mspt} = 1 \qquad \forall m,s,t \neq 0 \qquad (C8)$$

$$\sum_{t \in Shipavail_{ms}} \sum_{p \in Portuse_s} ON_{mspt} = 1 \qquad \forall m,s,t \neq 0 \qquad (C9)$$

$$A_{pt} \geq 0 \qquad \forall p,t \qquad (C10)$$

$$M_{pt} \geq 0 \qquad \forall p,t \qquad (C11)$$

$$OFF_{mspt} \in \{0,1\} \qquad \forall m,s,p,t \qquad (C12)$$

$$ON_{mspt} \in \{0,1\} \qquad \forall m,s,p,t \qquad (C13)$$

C. EXPLANATION OF THE MATHEMATICAL FORMULATION

The objection function measures total cost for all ammunition loading and unloading. Constraint sets (C1) and (C2) track tons of ammunition in each port at the start of every day. Constraint sets (C3) and (C4) similarly track the number of TCM in each port at the start of each day. Constraint set (C5) restricts the number of ships that are in port at the start of the day. Constraint set (C6) establishes the storage amount of ammunition in each port at the start of each day. Constraint set (C7) establishes the maximum number of TCM that can be stored in each port at the start of each day. Constraint set (C8) forces SNSKED to schedule all of the TCM and ammunition unloads. Constraint set (C9) forces SNSKED to schedule all the TCM and ammunition loads. Constraint sets (C10), (C11), (C12), and (C13) establish variables as nonnegative and binary.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. IMPLEMENTATION AND COMPUTATIONAL RESULTS

This chapter provides an overview of the data for the SNSKED test cases and the results of implementing SNSKED on various scheduling, ammunition availability, and port usage scenarios. The cost in SNSKED includes the price for fuel, tugboats and pilots. We pattern part of the SNSKED implementation using Meeks [1999]. We appropriated the ship loading times from historical workload averages [HVW 1998].

A. IMPLEMENTATION OF SNSKED

We implement SNSKED using the General Algebraic Modeling System [GAMS 2005] and the CPLEX solver [ILOG 2005]. Considering 19 ships for a single quarter at daily resolution, a typical SNSKED instance consists of approximately 1,700 equations, 5,700 continuous variables, 4,500 discrete variables, 19,000 non-zero elements and solves in less than three minutes.

B. NOTIONAL WINDOW OF AVAILABILITY

Table 3 shows a notional window of ship availability assembled from current scheduling directives [OPNAVINST 8010.12] and historical averages [HVW 1998]. With 19 of 35 SURFPAC ships, this schedule provides a reasonable approximation to the number of ships scheduled, amount of ammunition transferred, the number of TCM loaded, and the cost incurred by SURFPAC for any given quarter.

Ship Class	Ship Name	Mission	Days available to start
CG	BUNKER HILL	SURGE	Day 01 – Day 30
CG	MOBILE BAY	WESTPAC	Day 10 – Day 40
CG	LAKE CHAMPLAIN	SRA	Day 05 – Day 25
CG	PRINCETON	SRA	Day 40 - Day 60
DDG	JOHN PAUL JONES	SURGE	Day 01 - Day 30
DDG	FITZGERALD	SURGE	Day 31 - Day 60
DDG	STETHEM	SURGE	Day 01 - Day 30
DDG	BENFOLD	WESTPAC	Day 10 - Day 40
DDG	DECATUR	CD	Day 25 - Day 55
DDG	HIGGINS	SRA	Day 01 - Day 15
DDG	HOWARD	SRA	Day 45 - Day 60
FFG	GEORGE PHILIP	WESTPAC	Day 01 - Day 20
FFG	SIDES	IDTC	Day 21 - Day 40
FFG	CURTS	SRA	Day 35 - Day 60
LHA	TARAWA	WESTPAC	Day 30 - Day 60
LPD	OGDEN	WESTPAC	Day 01 - Day 20
LPD	DULUTH	SRA	Day 15 - Day 35
LSD	GERMANTOWN	WESTPAC	Day 01 - Day 20
LSD	COMSTOCK	SRA	Day 15 - Day 35

Table 3. Notional Window of Availability when a ship can begin the ammunition load or unload for the assigned mission. Missions include Inter-Deployment Training Cycle (IDTC), Surge Status (SURGE), Deployment to Western Pacific (WESTPAC), Counter Drug Operations (CD), and Ship Repair Availability (SRA). This represents a typical number of ships and missions per quarter. Days represent working days per quarter.

C. TCM AND AMMUNITION LIMITS

Table 4 shows the maximum storage limits of ammunition and TCM for every weapons port. In addition to these limits, there is also a war reserve ammunition storage area collocated with Seal Beach Weapons Station that is not included.

Weapons Station	Max tons of ammunition storage	Max number of TCM	Starting ammunition inventory in tons	Ammunition production per day in tons	Starting TCM inventory	TCM production per day
San Diego	1,000	0	0	0	0	0
Fallbrook	10,000	0	1,000	10	0	0
Seal Beach	10,000	1,000	1,000	10	30	2
VERTREP San Diego	0	0	0	0	0	0
VERTREP WESTPAC	0	0	0	0	0	0

Table 4. TCM and ammunition storage limits for all ports. Initial inventory of TCM and ammunition is assigned. Also establishes the production capacity for TCM and ammunition per day. Storage limitations do not include War Reserve storage capabilities at any port.

D. INITIAL IMPLEMENTATION

Using data from Tables 2, 3, and 4, we use current scheduling rules of thumb to obtain a reasonable schedule (called the Current Schedule). This results in a realistic quarterly cost of 3.5 million dollars. (This is very close to actual fuel, tugboat and pilot cost incurred at SURFPAC in a typical quarter for ammunition loadings.) Table 5 and Figure 6 summarize the quarterly cost improvements achieved by SNSKED using various changes from the current schedule. Table 5 shows the ability to save up to 1.4 million dollars per quarter. We provide details about each change, or scenario, in the paragraphs below.

Type of scenario	Quarterly Costs
Current Schedule	$3,536,000
Optimized Schedule	$2,960,000
Optimized with SD UNREP	$2,960,000
Optimized with SD Ammo Improvements	$2,840,000
Optimized with WESTPAC UNREP	$2,708,000
Optimized with SD Ammo & TCM Improvements	$2,084,000
Optimized with Efficiencies	$2,076,000

Table 5. SNSKED schedules starting with Current Scheduling, improving quarterly costs by differing ammunition inventories, ammunition transfer restrictions, port improvements and ammunition inventories.

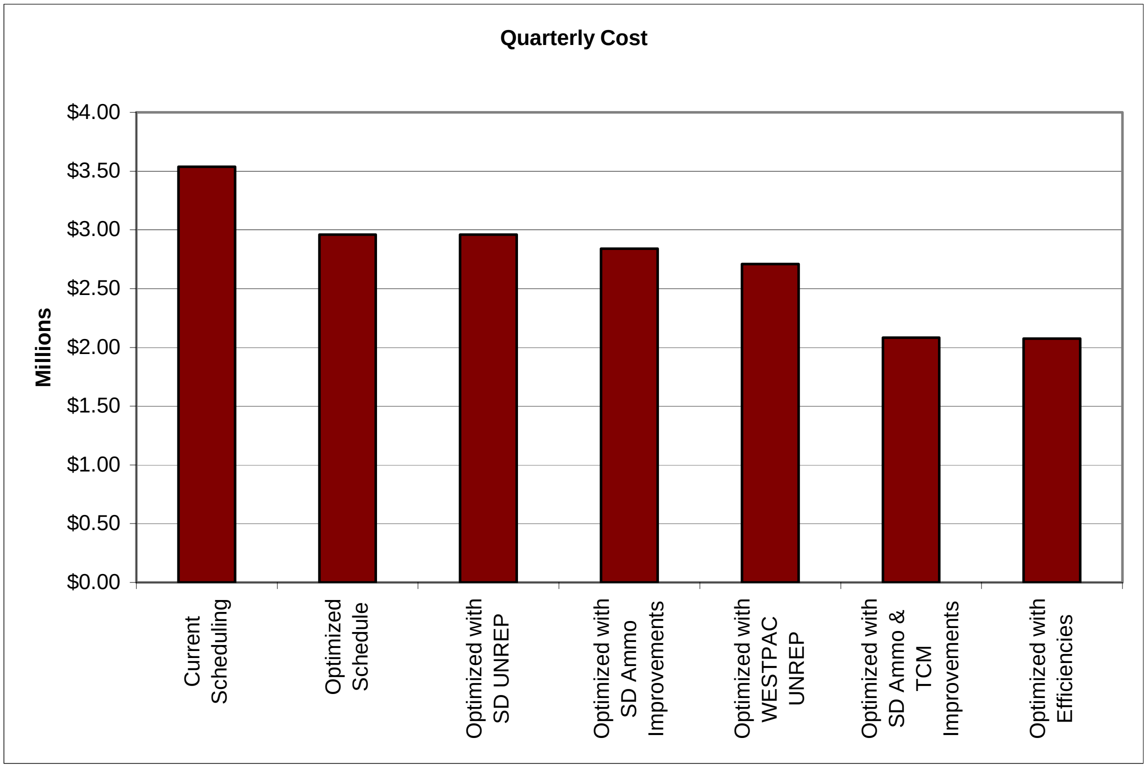

Figure 6. Graphical representation of Table 5. This graph shows the monetary savings that are available under different scenarios.

With no changes to port capacity or ammunition inventories, (Optimized Schedule), a savings of over 500,000 dollars per quarter is achievable by using an optimized schedule provided by SNSKED. In practice, it might be difficult to realize all the savings because ammunition loading schedules typically change numerous times prior to execution. The cost savings offer optimized comparison for the differing scheduling policies and changes to ammunition inventories and/or port facilities.

The added capability of doing VERTREP and/or Underway Replenishments (UNREP) in the San Diego operating area (shown in Tables 6 and 7, Optimized with San Diego UNREP) provided no savings over the optimized schedule. Given the assumed high costs of VERTREP and UNREP operations in San Diego, they are not viable options. To accomplish UNREP, a T-AOE is included with a maximum capacity of 10,000 tons of ammunition and an initial stock of 1,000 tons. The cost of repositioning a T-AOE to San Diego, even temporarily, made this option not cost effective (Table 6).

The high cost associated with helicopter VERTREP operations from Naval Air Station North Island greatly adds to the cost of this option.

Type of scenario	Quarterly Costs
Current Schedule	$3,536,000
Optimized Schedule	$2,960,000
Optimized with SD UNREP	$2,960,000

Table 6. SNSKED schedules comparing Current Schedule and Optimized Schedule to Optimized Schedule with San Diego UNREPs.

Weapons Station	**Max tons of ammunition storage**	**Max number of TCM**	**Starting ammunition inventory in tons**	**Ammunition production per day in tons**	**Starting TCM inventory**	**TCM production per day**
San Diego	1,000	0	0	0	0	0
Fallbrook	10,000	0	1,000	10	0	0
Seal Beach	10,000	1,000	1,000	10	30	2
VERTREP San Diego	***10,000***	0	***1,000***	0	0	0
VERTREP WESTPAC	0	0	0	0	0	0

Table 7. SNSKED starting conditions with additional VERTREP capability in San Diego Area. Compared to Table 4 the italicized regions are the only changes.

Another option is to increase the capability of the San Diego Weapons Station. By adding 500 tons of ammunition inventory to San Diego, (shown in Table 9, Optimized with San Diego Ammunition Improvements), the optimized schedule allows for an additional savings of over 100,000 dollars over the optimized schedule. This savings, due to reduced fuel cost, is achieved by scheduling more FFG ammunition loading and unloading in San Diego (Table 8). To accomplish this, additional staffing and equipment would be required in San Diego. Assuming those costs are reasonable, long-term savings could be achieved.

Type of scenario	Quarterly Costs
Current Schedule	$3,536,000
Optimized Schedule	$2,960,000
Optimized with SD Ammo Improvements	$2,840,000

Table 8. SNSKED schedules comparing Current Schedule and Optimized Schedule to Optimized Schedule with San Diego Ammunition Improvements.

Weapons Station	Max tons of ammunition storage	Max number of TCM	Starting ammunition inventory in tons	Ammunition production per day in tons	Starting TCM inventory	TCM production per day
San Diego	1,000	0	***500***	0	0	0
Fallbrook	10,000	0	1,000	10	0	0
Seal Beach	10,000	1,000	1,000	10	30	2
VERTREP San Diego	0	0	0	0	0	0
VERTREP WESTPAC	0	0	0	0	0	0

Table 9. SNSKED starting conditions with additional 500 tons of ammunition in San Diego. Compared to Table 4, the italicized region is the only change.

By using available space on the T-AE in Fifth Fleet (Table 10 and 11, Optimized with WESTPAC Ammunition Improvements), a savings of more than 200,000 dollars is possible over the optimized schedule. We assume the cost of this improvement is minimal, because both ships would be underway in the same area of operation without incurring additional costs. Requiring a T-AE to get underway for the sole purpose of transferring ammunition to a single ship eliminates any potential savings because of additional pilot, tugboat and fuel costs.

Type of scenario	Quarterly Costs
Current Schedule	$3,536,000
Optimized Schedule	$2,960,000
Optimized with WESTPAC UNREP	$2,708,000

Table 10. SNSKED schedules comparing Current Schedule and Optimized Schedule to Optimized Schedule with WESTPAC UNREPs.

Weapons Station	Max tons of ammunition storage	Max number of TCM	Starting ammunition inventory in tons	Ammunition production per day in tons	Starting TCM inventory	TCM production per day
San Diego	1,000	0	0	0	0	0
Fallbrook	10,000	0	1,000	10	0	0
Seal Beach	10,000	1,000	1,000	10	30	2
VERTREP San Diego	0	0	0	0	0	0
VERTREP WESTPAC	***10,000***	0	***1,000***	0	0	0

Table 11. SNSKED starting conditions with additional VERTREP capability in WESTPAC Area. Compared to Table 4 the italicized regions are the only changes.

Additional improvements to the capability of the San Diego Weapons Station are also considered. Specifically, improvements to the San Diego ammunition pier, increasing ammunition storage to 1,500 tons, improving TCM storage to 500, and adding an additional 50 TCM in inventory (Tables 12 and 13, Optimized with San Diego TCM and Ammunition Improvements) save over 800,000 dollars per quarter over the optimized schedule. The additional inventory of TCM would be a one-time cost of approximately 50 million dollars [NOI 2005]. The placement of this large inventory of TCM in San Diego would allow SURFPAC to save on fuel used in transit to Seal Beach.

Type of scenario	Quarterly Costs
Current Schedule	$3,536,000
Optimized Schedule	$2,960,000
Optimized with SD Ammo & TCM Improvements	$2,084,000

Table 12. SNSKED schedules comparing Current Schedule and Optimized Schedule to Optimized Schedule with San Diego Ammunition and TCM Improvements.

Weapons Station	Max tons of ammunition storage	Max number of TCM	Starting ammunition inventory in tons	Ammunition production per day in tons	Starting TCM inventory	TCM production per day
San Diego	***1,500***	***500***	0	0	***50***	0
Fallbrook	10,000	0	1,000	10	0	0
Seal Beach	10,000	1,000	1,000	10	30	2
VERTREP San Diego	0	0	0	0	0	0
VERTREP WESTPAC	0	0	0	0	0	0

Table 13. Improve San Diego TCM and Ammunition. Compared to Table 4, the italicized regions are the only changes.

Efficiency improvements (Table 14, Optimized with Efficiencies) provide the most savings with perhaps the least upfront costs. We achieve this savings by reducing the time required (shown in Table 2) to load a CG and DDG from three days to two days, reducing the time required for a FFG from one day to half a day, and reducing the time for a LHA and LHD from five days to four days. We accomplish these efficiencies by implementing the new SURFPAC standardized deployment loads and utilizing the unused space on the forward deployed T-OE and Carrier Strike Group T-AOE. A set loading amount and schedule would allow AMMOPAC and SURFPAC to better plan, organize, and prepare all ammunition loads to save time and money.

Type of scenario	Quarterly Costs
Current Schedule	$3,536,000
Optimized Schedule	$2,960,000
Optimized with Efficiencies	$2,076,000

Table 14. SNSKED schedules comparing Current Schedule and Optimized Schedule to Optimized Schedule with Efficiencies.

E. COMBINING EFFICIENCIES

Because efficiencies like standardized TCM and ammunition loadings are being implemented, this thesis explores what other combinations of efficiencies could be included to save costs. The results are listed in Table 15 and Figure 7. These additional options provide over one million dollars in potential savings.

Combination of Improvements	Quarterly Costs
Current Schedule	$3,536,000
Optimized Schedule	$2,960,000
Current Scheduling with Efficiencies	$2,560,000
Optimized SD Ammo with Efficiencies	$2,076,000
Optimized WESTPAC UNREP with Efficiencies	$1,884,000
Optimized SD Ammo & TCM with Efficiencies	$1,524,000

Table 15. Additional improvements with efficiencies that provide an additional one million dollars in savings.

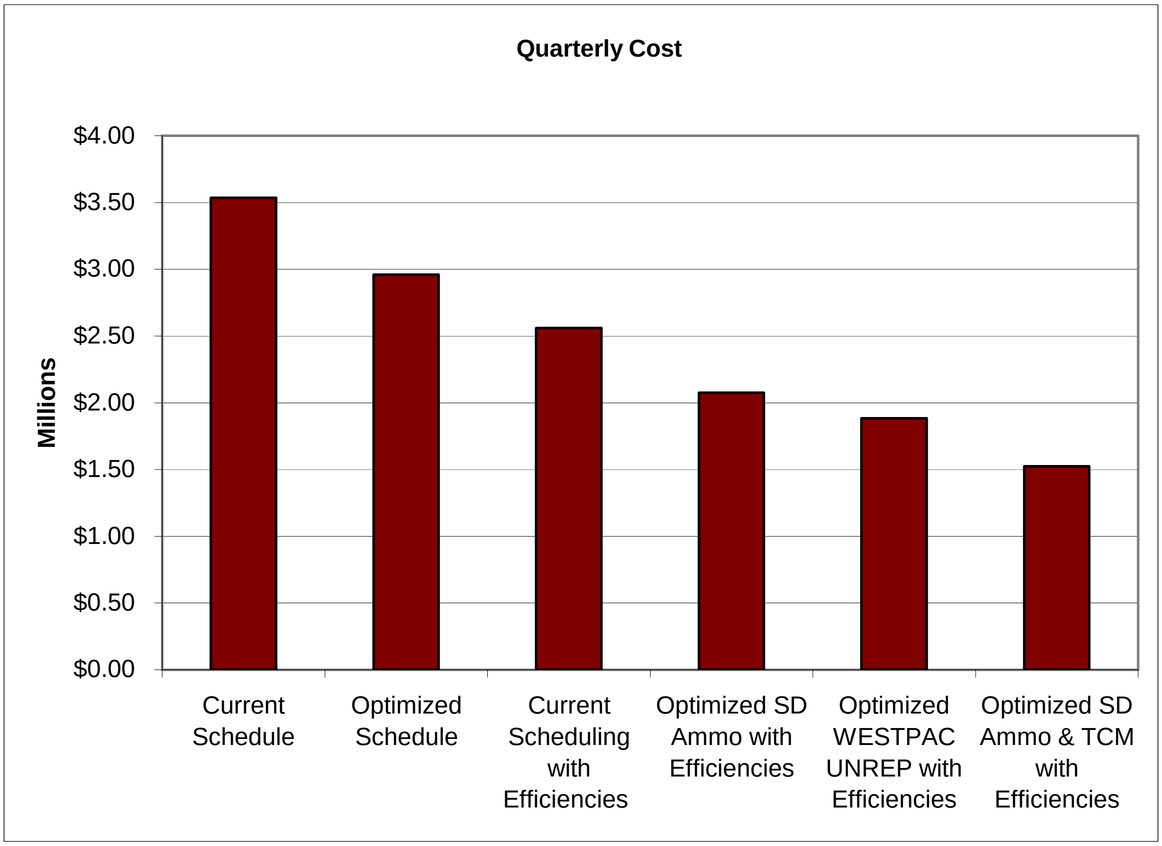

Figure 7. Graphical representation of Table 15. This graph shows the monetary savings that are available to SURFPAC after full implementation of efficiencies.

We first combine efficiencies with the scheduling rules of thumb described earlier. This combination (Current Scheduling with Efficiencies) provides over 400,000 dollars in savings over the optimized schedule. Again, we achieve time savings by using

a set load amount for all ships of the same class going on the same or very similar missions. We gain the savings in ammunition loading time by storing more ammunition on the T-AOE or T-AE.

Next, we combine efficiencies with ammunition inventory improvements of 500 tons of additional ammunition (Table 9, Optimized San Diego Ammunition with Efficiencies) in San Diego and attain a savings of almost one million dollars compared to the optimized schedule. This along with the additional capacity in San Diego means we conduct all FFG ammunition movements in San Diego.

The combination of efficiencies with WESTPAC UNREP (Table 11, Optimized WESTPAC UNREP with Efficiencies) produces a savings of over one million dollars compared to the optimized schedule. We achieve this savings by quickly transferring ammunition to T-AE or T-AOE while on deployment so only the TCM need to be unloaded after returning from deployment.

The final improvement (Table 13, Optimized San Diego TCM and Ammunition with Efficiencies) combines San Diego improvements to TCM and ammunition abilities with efficiencies. We speculate that a savings of over one and half million dollars per quarter is possible over the optimized schedule and that SURFPAC could use these savings to offset the cost of improvements to San Diego ammunition pier capabilities and ammunition inventory increases.

V. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

This thesis presents an integer linear program model (SNSKED) that recommends a ship scheduling and ammunition-positioning schema for SURFPAC. SNSKED minimizes the cost of shuffling ships and ammunition between ports, while adhering to staffing and equipment requirements, port throughput, and ship deployment schedules. Key features of the model include: the ability to include all classes of ships, all ammunition port facilities, and all types of ammunition transfers; the capacity to investigate various TCM stationing strategies; and the flexibility to explore various ship scheduling scenarios.

In summary, this thesis demonstrates that SNSKED shows the potential to save money and serve as a tool to analyze the impact of changes in policies governing SURFPAC and AMMOPAC operations. SNSKED also analyzes the impact of changes to ammunition port facilities and quantifies long-term savings that can be realized by the U.S. Navy.

B. RECOMMENDATIONS

The U.S. Navy must make all attempts to optimally manage ship schedules and port capabilities to minimize cost. SURFPAC and AMMOPAC must work closely to jointly optimize the funds spent on ammunition loading and unloading and ammunition procurement to better use scare resources. The following is a list of topics recommended to further extend this thesis.

1. All PACFLEET ships and AMMOPAC facilities need to be included in SNSKED to optimally schedule and realize savings. Use of a similar scheduling program by PACFLEET and AMMOPAC could help realize additional savings.

2. SNSKED only allows certain ports to obtain new ammunition and this ammunition arrives at a specific rate. Further research needs to be done to determine if a better receipt scheduling process or better ammunition production process is possible.

3. Incorporate all SURFPAC and AMMOPAC labor costs and port improvement costs into SNSKED.

4. Develop a business cost analysis of all ammunition facilities and the cost of improvements recommended to determine where to spend scarce base improvement dollars to best improve the fleet capabilities.

LIST OF REFERENCES

Bouveron, M. E., "An Analysis of the Ordnance Offload/Onload Cost of Pacific Fleet Large Deck Amphibious Assault Ships (LHA and LHD) Homeported in San Diego", Master's Thesis, Naval Postgraduate School, Monterey, California, December 1995. [Bouveron 1995].

Brown, G. G., Dell, R. F., and Farmer, R. A. "Scheduling Coast Guard District Cutters", INTERFACES 26 March-April 1996. [Brown et al. 1996].

Brown, G. G., Goodman, C. E., and Wood, R. K., "Annual Scheduling of Atlantic Fleet Naval Combatants", *Operations Research*, v. 38, pp. 249-259, March-April 1990. [Brown et al. 1990].

Dantzig, G. B. and Fulkerson, D. R., "Minimizing the Number of Tankers to Meet A Fixed Schedule", Naval Research Logistics Quarterly, volume number 3. [Dantzig and Fulkerson 1954].

Farmer, R. A., "Scheduling Coast Guard District Cutters", Master's Thesis, Naval Postgraduate School, Monterey, California, June 1992. [Farmer 1992].

General Algebraic Modeling System 2005, www.gams.com, Retrieved March 14, 2005. GAMS Development Corp 1217 Potomac Street, NW Washington DC 20007. [GAMS 2005].

Global Security photos, Weapons Station Seal Beach, MK41 VLS, Naval Station San Diego and Weapons Station Fallbrook courtesy [www.globalsecurity.org]. Retrieved March 14, 2005. [Global 2005].

Goodman, C. E., "Annual Scheduling of Atlantic Fleet Naval Combatants", Master's Thesis, Naval Postgraduate School, Monterey, California, March 1985. [Goodman 1985].

Google Map, Southern California courtesy [www.maps.google.com]. Retrieved March 14, 2005. [Google Maps 2005].

Historical Variable Workload for all Weapons Stations for Ammunition Ordinance Director Pacific. Survey conducted by Ammunition Management Office Pacific, September 1998. [HVW 1998].

ILOG Inc, www.ilog.com, Retrieved March 14, 2005. ILOG Inc. 1080 Linda Vista Ave. Mountain View, CA 94043, [ILOG 2005].

Lima, N. R., "A Column Generation Technique for a Crises Deployment Planning Problem", Master's Thesis, Naval Postgraduate School, Monterey, California, September 1988. [Lima, 1988].

Meeks, B. P., "Optimally Scheduling EA-6B Depot Maintenance", Master's Thesis, Naval Postgraduate School, Monterey, California, September 1999. [Meeks 1999].

Morton, D. P., Salmeron, J. and Wood, R. K., "A Stochastic Program for Optimizing Military Sealift Subject to Attack", Graduate Program, The University of Texas at Austin. [Morton et al. 2002].

Naval Base Coronado Weapons Program, Functions and Tasks Mission Funded, January 1986. Bldg. 239, Code 210J, 800 Seal Beach Blvd., Seal Beach, California 90740. [NPCWP 1986].

Naval Base Coronado Weapons Program, Mission Statement, March 2004, Commander Pacific Fleet. [NPCWPMS 2004].

U.S. Navy Office of Information, www.chinfo.navy.mil/navpalib/factfile/missiles/tacttom.html. Retrieved March 14, 2005. [NOI 2005].

Office of the Chief of Naval Operations instruction 8010.12F, *Naval Conventional Ordnance Operational Logistics Policy*, Office of the Chief of Naval Operations, 28 March 2000. [OPNAVINST 8010.12].

Ratliff, H. D. and Nulty, H. D., School of Industrial and Systems Engineering, Georgia Institute of Technology PDRC 86-11, *Interactive Optimization Methodology for Fleet Scheduling*, September 1986. [Ratliff and Nulty 1986].

Ratliff, H.D., School of Industrial and Systems Engineering, Georgia Institute of Technology, *Development of a Basic Methodology for Use in Analyzing Feasible Scheduling and Rating Schemes*, June 1981. [Ratliff 1981].

Ronen, D., "Cargo Ships Routing and Scheduling: Survey of Models and Problems," European Journal of Operational Research, v. 12, pp. 119-126, February 1983. [Ronen 1983].

Sibre, C. E., "A Quadratic Linear Programming Approach to Ship Scheduling for the U.S. Coast Guard", Master's Thesis, Naval Postgraduate School, Monterey, California, June 1977. [Sibre 1977].

U. S. Department of State, 1954 United States – Republic of Korea Mutual Defense Treaty, www.state.gov/r/pa/ei/bgn/2800.htm. Retrieved March 14, 2005. [DOS 2005].

Vaughan, R. J., Private Conversation with Roscoe J. Vaught (TMCM), Naval Surface Force U.S. Pacific Fleet, June 2004. [Vaughan 2004].

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Professor Robert Dell
   Naval Postgraduate School
   Monterey, California

4. CDR Robert Heck
   COMNAVSURFPAC
   San Diego, California

5. CDR Glenn Lintz
   Naval Postgraduate School
   Monterey, California